# Izmir Metro: Story of a Successful Engineering Project

Emre Aykar

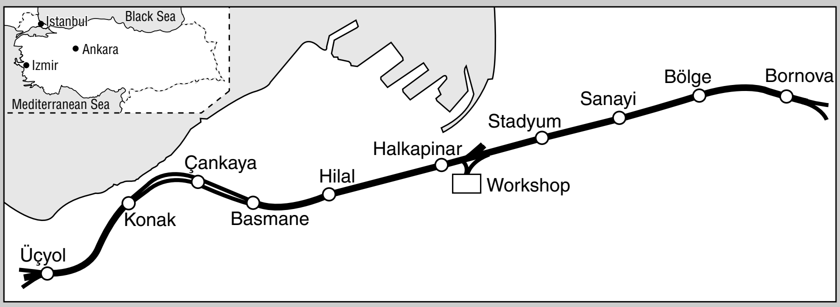
## Introduction

The Izmir Metro is a major milestone in Turkey's urban transportation both as a significant infrastructure project in terms of engineering and construction and because the design and implementation of this hugely successful project gave rise to many other urban rail systems in important cities such as Adana, Bursa, Antalya and Eskişehir in Turkey.

In the 1960s, the city of Izmir had a population of about 1 million. This figure tripled over the next 30 years due to enormous migration. As a result, municipal authorities initiated a transportation study in 1988 to handle the spiralling population. The resultant Transportation Master Plan consists of a 43-km rail network around Izmir Bay to be implemented in four stages with the first 11.5-km stage put out to tender in mid-1992. A contract was signed in early 1993 with site hand-over in early 1994. Construction started in 1995 and was completed successfully in less than 4 years. Testing began in September 1999 and the system came into service in May 2000 as Izmir's population reached 3.4 million.

The total cost of the turnkey, design and built project was US$600 million handled as a joint project of the Yapi Merkezi–AdTranz Consortium. Yapi Merkezi was the main contractor for all design and civil works (tunnels, bridges, viaducts, stations, tracks, infrastructure, depots and workshops) as well as the third-rail power system. ABB-AdTranz of Sweden supplied the rolling stock and installed the power-supply, signalling, telecommunication and remote-control systems.

**Alignment of Stage 1 (11.5 km) of Izmir Metro**




## About Izmir

The city of Izmir has an area of 12,000 km$^2$ located on the mid-Aegean coast of western Turkey (38°24′ N and 27°10′ E). It has a large bay about 40-km long and between 2- and 7.5-km wide that has been a major trade hub for millenia. The city is at the head of a long narrow gulf cut through by ships and yachts. The climate is mild in winter and the heat of summer is relieved by constant and refreshing sea breezes. The city behind the palm-lined shore front promenades climbs gently in horizontal terraces up the slopes of the surrounding mountains.

Izmir's history goes back to 3000 B.C. with the discovery of the Zeus Altar in Pergamon (Bergama), the Artemis Temple, and parts of the ancient city of Ephesus. The earliest remains are contemporary with the second civilization of Troy when the city was known as Smyrna in ancient Greek. Alexander the Great (350–323 B.C.) sacked the city in 333 B.C. followed by a Roman period from around 100 B.C. By the 9th century, Izmir was an important naval base and dockyard in the Byzantine Empire (312–1453) and it remained an important international port under the Nicaean Empire (1204–61), finally becoming part of the Ottoman Empire (1299–1923) in 1426. The shore fort was rebuilt by Mehmed the Conqueror after an attack by the Venetians in 1472. Izmir's location on a huge natural harbour has kept it at the forefront of trade and culture for millenia and since the founding of the Turkish Republic in 1923, it has become the third biggest city in the country with fast-developing foreign trade and industry based on agriculture, tourism, culture and educational activities.

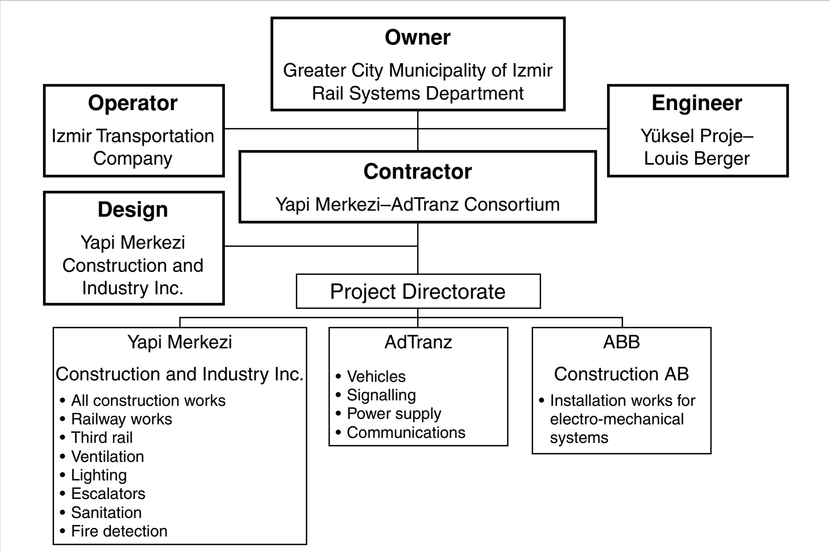
## Transportation Study

By 1990, Izmir's existing transportation network could no longer meet the needs of the growing population, especially because the centre corridor was squeezed on both sides by the restricting topography. By 1990, 400,000–600,000 passengers were passing each day through the city centre with a projected figure of 1.6 million passengers in 2010. The old transportation network was inefficient, dangerous, uneconomic and uncomfortable; the ridership potential coefficient (coefficient of ridership x city population = daily transport number) was 1.23 in 1990 and projected to rise to 1.50 in 2010.

The city authorities realized that the system had to be changed as soon as possible by developing an effective public transportation system and it was soon decided that a better structure could only be achieved by building an inner-city rail system with a high capacity based on modern technology that could adapt flexibly and easily to the existing structure of the city. It also had to be built and opened quickly.

The lines suggested in the Transportation Master Plan were discussed and it was proposed to build a 43-km rail network

**Project Organization**




**Project Specifications**

| | |
|---|---|
| Construction period | 1995–2000 |
| Project value | US$600 million |
| Total length | 11.6 km |
| Number of Stations | 10 |
| Underground | 4 |
| Viaduct | 2 |
| Levelline | 4 |
| Peak capacity | 45,000 passenger/h in each direction |
| Minimum headway | 2 minutes |
| Number of cars per train | 3 to 5 |
| Fleet size | 45 cars |
| Power supply | Third rail (750 Vdc) |
| Maximum speed | 80 km/h |
| Schedule speed | 40 km/h |
| Station platform height | 88 cm |
| Platform length | 125 m |
| Workshop building | 10,500 $m^2$ |
| Depot area | 55,300 $m^2$ |

based around the Üçyol–Konak–Basmane–Halkapınar line where the public transportation density in 2010 was forecast to be maximum. Studies on passenger density and construction feasibility indicated the need to build the network in four stages.

## Civil Engineering Works

The Yapi Merkezi–AdTranz Consortium won the bidding for all phases of the Izmir Light Rail Transit System (LRTS) from design to training operating staff. The complex geology and changing city topography necessitated use of different construction methods (four tunnelling methods) along the 11.5-km alignment. Moreover, Izmir is in an active earthquake zone, presenting Yapi Merkezi with major challenges in the design and construction phases. Special measures had to be taken to bear potential earthquake loads.

The 1.7-km long tunnels—including the Üçyol deep station platform—were bored through andesite using the New Austrian Tunnelling Method (NATM). Since the Üçyol platform is 36 m below ground level (–36 m GL), the escalator tunnels leading to the cut-and-cover ticket halls were also bored from below by NATM.

At the other end of the alignment, the approximately 1-km long tunnel leading to the Bornova underground station as well as the station itself were excavated by the cover-and-cut method selected because the complex roads and highways in the area prevented leaving open pits for long periods of time.

The Earth Pressure Balance Method (EPBM) was used for the two twin tunnel tubes connecting the Konak, Çankaya and Basmane stations. The four tubes total 2.75 km in length with a finished diameter of 5.7 m. The excavated diameter was 6.55 m with an overburden thickness of 6 to 14 m. The geology consists of various formations, including gravelly sands to sandy silts to silty clays with no boulders or basement rock formations. Sea level (SL) in the area is about –3 m GL and the ground water level is very close to SL. Lenses of sandy gravels had very high artesian potential and the clay water content was nearly at the liquid limit. This difficult geology necessitated cutting the the twin tunnel tubes with a full face, shielded and watertight EPBM tunnel boring machine designed specifically for Izmir's geology and the Metro's requirements. The fourth drive saw a record daily advance of 28.8 m.

The three underground stations at Konak, Çanaya and Basmane were excavated by the cut-and-cover method. In this section, the track level is between –10 and –13 m SL with a mixed geology including a wide variety of materials like gravelly sands to sandy silts to silty clays. The Konak and Çankaya stations are close to land reclaimed over many centuries from the sea with a deep artificial fill of up to 6 m. As a result, 0.8- to 1.2-m thick diaphragm walls ranging in depth from 25 to 33 m were built as groundwater barriers.

Five of the 10 stations are underground, two are elevated, and three are at grade. Viaducts constitute about 2.5 km of the total length with about 3.2 km of lines at grade. Various prefabrication techniques were used when possible to shorten overall construction time. The structural system is composed of bored piles, cast-in-situ foundations and columns, and prestressed prefabricated concrete beams. Besides the aesthetic values, the construction was completed ahead of schedule and a fairly economical solution was obtained by developing and using

### Construction Specifications

| | | |
|---|---|---|
| **Types of structures** | | |
| Between Üçyol and Konak | | |
| Deep tunnel (Nene Hatun Tunnel) constructed by NATM | 1,700 | m |
| Between Konak and Basmane | | |
| Twin tunnels (Ümmühan Ana Tunnel) constructed by EPBM method | 1,400 | m x 2 |
| Cut & Cover tunnels (with diaphragm walls) | 1,100 | m |
| Between Basmane and Bornova | | |
| Viaducts | 2,800 | m |
| At grade/box structures | 3,600 | m |
| Cut & Cover and cut structures | 1,000 | m |
| Total length | 11,600 | m |
| **Main construction works** | | |
| Excavation (including tunnels) | 860,000 | $m^3$ |
| Fill (including cement stabilization) | 130,000 | $m^3$ |
| Concrete (including prestressed precast concrete) | 310,000 | $m^3$ |
| Steel structures (high and normal strength) | 12,000 | tonnes |
| Railway line (single track) | 37,000 | m |
| Third rail (aluminium alloy rail) | 26,000 | m |
| **Alignment criteria** | | |
| Main line Rmin | 250 | m |
| Depot Rmin | 30 | m |
| Stations Rmin | 600 | m |
| Max. lateral acceleration | 0.65 | $m/s^2$ |
| Required lateral acceleration | 0.35 | $m/s^2$ |
| Max. superelevation | 140 | mm |
| Min. transition curve length | 0.4 | h |
| Superelevation ramp | 1/400 | |
| Max. grade | 5% (on the main line), 0% (at workshop), 0.20% (at stations) | |
| Vertical curve | R=(V2/2)>2000 m | |
| Track gauge | 1,435 mm | |
| Rail type | S 49 (BV 49) vignole - RI 56 grooved | |
| Rail connection | Aluminothermic welding | |
| Sleeper connection | Vossloh elastic connection | |
| Sleepers | Prestressed concrete; wooden at special areas | |
| Track bed | Ballast | |
| Switches | 1:9 R = 300, 1:9 R = 190 on main line, 1:6 R = 100 at workshop | |
| **Architectural design criteria** | | |
| Safe and comfortable passenger circulation and system operation | | |
| Modular | | |
| Conformance to local environment | | |
| Integration with urban formation and historical background | | |
| Integration with other transport modes | | |
| Constructability | | |
| Durable, low-maintenance materials | | |
| Consideration of future development | | |
| **Structural design criteria** | | |
| Earthquake resistant | | |
| Elasticity and strength | | |
| Light structures | | |
| Design loads in conformance with international standards | | |
| Primary (dead and live loads, centrifugal, settlement of supports, shrinkage and creep, earth pressure) | | |
| Temporary (acceleration, deceleration, hunting force, thermal forces, wind, snow) | | |
| Special loads (seismic loads, collision, erection) | | |
| Extensive geotechnical investigations and evaluations | | |
| Continuity in structural systems | | |
| Aesthetic viaducts | | |
| Efficient construction methods | | |
| Technically sound and economically feasible structures | | |

prestressed precast girders with a high efficiency factor.

Üçyol, the first station on the Izmir LRTS is a deep tunnel station at –35 m GL. The design allows a smooth flow of pedestrian traffic and includes adequate space to accommodate both normal and emergency passenger loads. The viaduct stations with side platforms and ticket halls at grade have the same technical standards as the other stations. Despite the necessity to meet all the challenges of a viaduct, human dimensions are well respected. The shape of the columns supporting the beams, the height and even the design of the guard rails are all designed to prevent a bulky appearance that might disturb the surroundings.

The 57,000-$m^2$ depot is designed to handle all maintenance and operational needs; it has a capacity of 80 vehicles and an enclosed maintenance workshop area of 10,500 $m^2$. The main concern was to enable vehicles to enter and exit the depot through a grade-separated line without interfering with main-line traffic. There is also an emergency entrance line for use in case of a system failure.

## Vehicle Specifications

AdTranz was responsible for the rolling stock and the signalling, power-supply and communication systems. (ABB Traction was subsequently purchased by Daimler and became AdTranz only to be purchased later by Bombardier.)

The Izmir Light Rail Vehicle (LRV) is tailor-made for the LRTS. It is 3760-mm high (from head of rail), 2650-mm wide, and 23,500-mm long (over couplers) with a maximum speed of 80 km/h. The maximum acceleration is 1.0 m/s with a seating capacity of 44 and a standing capacity of 140.

All LRVs are self-powered and the drive and braking systems (with wheel-slip protection) are controlled by on-board computer. A train consists of two to five vehicles with driver's cabin at each end. The LRV is a six-axle articulated unit with three bogies. The first and last bogies are powered while the articulated bogie is trailing.

The auxiliary power system is based on a static converter-inverter, supplied from a 750-Vdc third rail and supplying 3-phase x 400 Vac at 50 Hz for compressor, fans, lights, battery charging, etc. The 24-Vdc battery system supplies the on-board computer as well as other safety systems such as automatic train control (ATC), train radio, passenger displays, emergency lights, etc. The tunnel safety aspects have top priority.

Çankaya Station (Yapi Merkezi Construction and Industry)

EPBM Tunnel between Konak and Basmane stations (Yapi Merkezi Construction and Industry)

Sanayi Station (Yapi Merkezi Construction and Industry)

Halkapinar Station (Yapi Merkezi Construction and Industry)

Workshop area between Halkapinar and Stadyum stations (Yapi Merkezi Construction and Industry)

## Financing

The Izmir Metro is a good example of the successful application of structured financing in Turkey. The project—Izmir's biggest to date—was fully financed by international banks and financial institutions (Standard & Chartered Bank for Export Credits Guarantee Department (ECGD) guaranteed portion and commercial loan; Bankers Trust Company for commercial loan; Skandinavska Enskilda Banken for the Swedish Export Credits Guarantee Board (EKN) guaranteed portion; Nordic Investment Bank and BHF Bank for AKA) with guarantees from the Turkish government.

## Conclusion

The Izmir Transportation Company, an affiliate of the Greater City Municipality of Izmir took over the Izmir Metro in May 2000 after a 1-year commissioning period. Since then, the Izmir Metro has carried more than 150 million people in safety and comfort with no technical problems. The construction site was visited by many international experts who commented favourably on the work. Dr Pierre Laconte, UITP Secretary General said, 'Members of the UITP Rail Systems Committee (see pp. 4–9) have been very impressed today by the various structures being built here. The modern workshop building and fully protected line are especially worth mentioning.' Mr Takashi Takeyama, Head of the Engineering Department of the Japanese Mass Transportation Center said, 'We have seen a perfect metro system construction with very detailed studies and much valuable information collection.'

The final source of pride for Yapi Merkezi is that the company was ranked third by the *Engineering News Record* in the list of Top International Light Rail/Mass Transit Contractors for 1999. ■


### Emre Aykar

Mr Aykar is Partner and Chairman of Yapi Merkezi Construction and Industry Inc. He has a Master's degree in civil engineering from Bogazici University in Istanbul. He has a long career in the construction industry and is a specialist in concrete technology, prefabrication, fire engineering and rail systems. His major rail-related projects include the Istanbul Light Metro, Izmir Metro and the Antalya and Eskişehir tramway systems.